Characterization of the range dependence of an ocean environment to reduce acoustic estimation time

Steven M. Dennis and J. Paquin Fabre
Naval Research Laboratory
Stennis Space Center, MS 39529, USA

Abstract-**As computer capabilities continue to increase, characterization of the oceanic environment improves both spatially and temporally. This oceanographic information (specifically sound velocity) is often used to make acoustic predictions, but wide-area acoustic predictions have been limited by computation time. Currently, in order to characterize an area acoustically, propagation loss estimates are computed for equally spaced grid points over a large area. Acoustic models have become fairly fast, however, when doing multiple source and receiver configurations, multiple frequencies and several range dependent bearings for many grid points, the task can become computationally prohibitive. Range independent predictions are significantly faster than range dependent predictions, but can under-represent the acoustic propagation due to features in the sound speed structure where the environment is non-adiabatic (range dependent). Adiabatic normal mode calculations can also be done fairly quickly (faster than range independent transmission loss predictions) but for the same reason, still do not provide the best estimate of the acoustics. A method is developed and presented here to compute normal modes for an environment and use them to determine how adiabatic that environment is. This is done by comparing the number of modes and the wave numbers computed for each sound speed profile, to those of neighboring profiles. If the nature of the mode functions changes significantly, the profile is flagged as non-adiabatic. Once the adiabatic determination is made, range dependent runs are computed for the areas that are shown to be non-adiabatic and range independent runs are computed for the adiabatic areas. This process reduces the amount of run time required to assess an area, while maintaining a high level of accuracy of the acoustic characterization of the whole area. This run time reduction can be significant for many areas of the world. Estimates of acoustic coverage (that is, the area for which acoustic transmission loss is below a threshold) of the area using the adiabatic measure are computed and compared to the full grid computation. This shows that taking advantage of the adiabatic areas to reduce the number of acoustic predictions required for an area still provides an acceptable estimate of the wide-area acoustic environment.**

I. INTRODUCTION

An overall characterization of the acoustic propagation conditions in an area can greatly facilitate the planning of an acoustic experiment. It is, however, very time consuming to compute acoustic propagation to and from many potential source and receiver locations for multiple locations on an area-wide grid. The computation can be done for each environment in a range independent manner to make a significantly faster estimate, but significant features can be mis-represented in areas where the propagation changes significantly due to the changes along its environmental path. Propagating acoustic normal modes can be computed fairly quickly and compared to the modes of their neighboring environments to determine how adiabatic, or range dependent, an environment is. Range independent runs can then be computed in weakly range dependent environments and range dependent runs can be computed where required by the complexity of the environment, thus reducing the run time required to characterize the environment. It is shown that a fairly simple implementation of this method can reduce run times by 25% or more.

II. METHOD

In order to acoustically characterize an environment, several environmental parameters are required. The sound velocity in the water column can be obtained from model estimates or measurements. The sediment description and bathymetry are generally obtained from databases, however, the sediment description can be developed by a geophysicist using historical and published geologic information. For the purposes of this paper, the sound velocity in the water column is generated using the Navy Coastal Ocean Model (NCOM) (Barron, et al. 2004) for an area in Monterey Bay at the time of the Autonomous Ocean Sampling Network-II (AOSN-II) experiment (Leslie, 2003). The geo-acoustic sediment description was developed as in Fulford (1993) and the bathymetry was extracted from the Digital Bathymetry Database – Variable resolution (DBDBV) (NAVO, 2007). An example sound velocity for a selected area off Monterey Bay at 100m depth with contoured DBDBV bathymetry is shown in Figure 1.

Next, the normal mode eigenvalues are computed for each grid point and compared to neighboring grid points to determine how adiabatic the environment is. This can be done in a number of ways. A normal mode model, for example Kraken (Porter, 2001) can be used. For this work, a faster, bounded elliptical modes (BEM) (Smith, 2007) method was used to predict the eigenvalues. This technique assumes the elliptical dependence of wave number on the mode number to estimate the modal wave numbers given the sound speed and sediment geo-acoustics. This method was compared to

0-933957-35-1

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Characterization of the range dependence of an ocean environment to reduce acoustic estimation time**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Stennis Space Center,MS,39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002047. Presented at the MTS/IEEE Oceans 2007 Conference held in Vancouver, Canada on Sep 29-Oct 4, 2007.

14. ABSTRACT
See Report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

eigenvalue predictions using the Kraken normal mode acoustic model (Porter, 2001) and was shown to be very close.

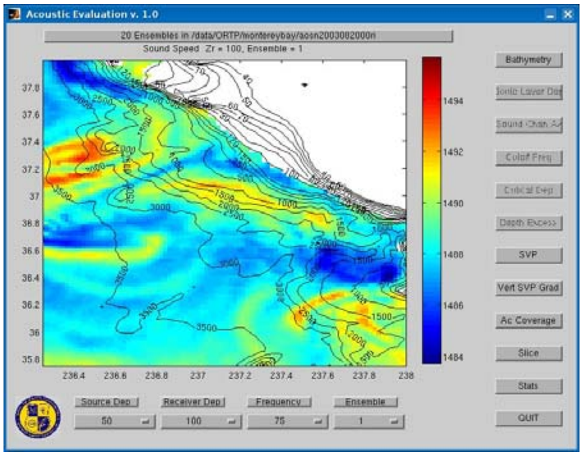

Figure 1. Example sound velocity for Monterey Bay area at a depth of 100m.

The parameters computed by the BEM were normalized to have equal weight and were then clustered using a simple k-means clustering algorithm (e.g. Gupta, et al., 2003). From each grid point, a great circle track is then computed in 8 directions to the maximum range (100km in this case), the cluster value is examined and if it changes along the track, that bearing at that grid point is considered to be non-adiabatic or range dependent. The results of the k-means clustering and track analysis for this area at 75 Hz are shown in Figure 2. For this example, 6 clusters were chosen and one (medium blue, upper right) is land. In Figure 2, if a bearing was non-adiabatic, a short line was plotted, for example in the lower left of the plot, several locations have only one or two non-adiabatic bearings, while in the center (orange) most of the grid points were non-adiabatic.

Once this analysis is complete, the environmental information is formatted for input to the Range Dependent Acoustic Model (RAM) (Collins, 1989). A source is placed at each grid location and multiple receivers are computed for each frequency at ranges along the selected tracks. The RAM was run range independently (single sound speed, bottom description and water depth) for each grid point that was flagged adiabatic and range dependently for the remaining grid points and bearings that were flagged non-adiabatic. Previously, every grid point was run range dependently. Using this adiabatic analysis, for this presented case 25% fewer runs were required and results are discussed below.

III. RESULTS

Because transmission loss (TL) from multiple sources to multiple receivers in many directions over a large area is hard to visualize, a metric known as acoustic coverage area (Dennis and Hemsteter, 2007) is computed for each grid point. This represents the area “seen” by an acoustic receiver due to the acoustic source given a figure of merit (FOM) (Urick, 1983) input by the user. That is, any TL that is less than the FOM (because TL is a loss) is considered covered and the area for that bearing segment is added to the total area for each grid point. This way, one number (coverage area) can be assigned to each grid point and therefore displayed more intuitively.

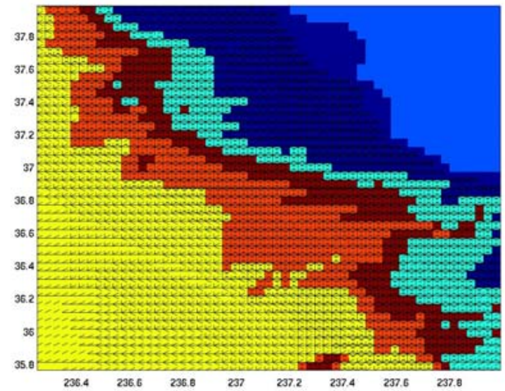

Figure 2. K-means clusters and range dependent analysis results for 75 Hz.

For the purposes of development and analysis of this method, every grid point was computed both adiabatic and non-adiabatic for multiple frequencies and receivers. The fully adiabatic estimate is given in Figure 3 for 75 Hz and a 100m receiver. This analysis shows two primary locations, around 37.2N, 236.4 (123.6W) and 36.4N, 237.8 (122.2W), with significant acoustic coverage. Figure 4 shows the fully non-adiabatic estimate of coverage which shows the same general areas of high coverage area, but with coverage values not as high. Figure 5 shows the results of both adiabatic and non-adiabatic estimates using the clustering analysis described above. This estimate took 25% less time than the full non-adiabatic estimate (Figure 4) and is very similar in accuracy. In order to get a broad-brush comparison of the accuracy of the different methods, the total coverage for the area at each depth was computed. These coverages can then be compared for each method (adiabatic, non-adiabatic, combined), assuming that the fully non-adiabatic answer is the most correct. The results of this comparison for 10 receiver depths are shown in Table 1. The combined coverage shows very good agreement with the non-adiabatic coverage for all depths.

Two other areas were examined using this method of analysis. An area in the Western Pacific ocean showed a 41% time savings using this method, the accuracy results for this case are similar (around ~2% or less for most depths). Therefore, in this case a reduction in run time of 41% only resulted in a ~2% less accurate answer. The third area analyzed was a much smaller, shallower shelf area off the US coast, this method resulted in a 5% reduction in run time, with similar accuracy results. The time savings of this case were not as significant as the other cases because the area was about twice the size of the acoustic model maximum range (so very few tracks were range independent), and because it was very shallow, so the clusters were scattered throughout the area giving mostly non-adiabatic tracks. Additionally, the coverages were very low across the area.

More time savings can be achieved with little reduction in accuracy by shortening the ranges, while maintaining the

exercise objectives. Additionally reducing the number of clusters can lead to time savings, though that could result in a reduction in accuracy.

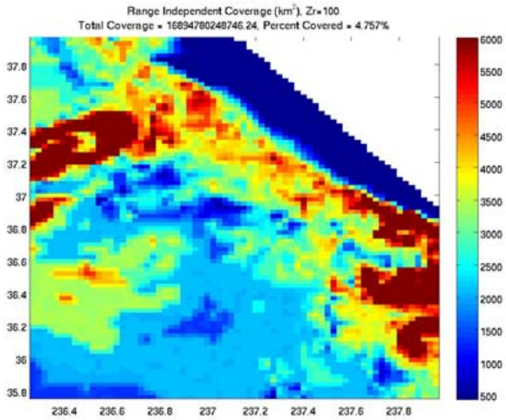

Figure 3. Full adiabatic analysis of acoustic coverage area at 100m for 75 Hz (units of area, m^2).

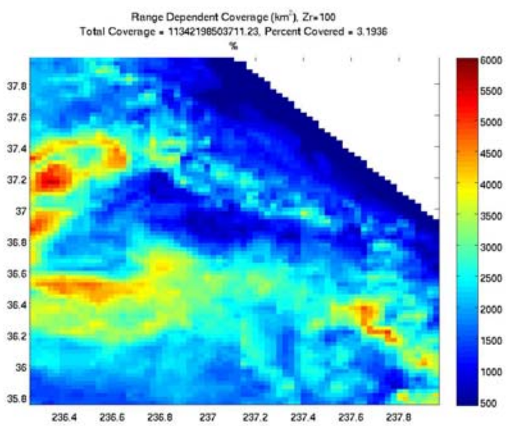

Figure 4. Full non-adiabatic analysis of acoustic coverage area at 100m for 75 Hz (m^2).

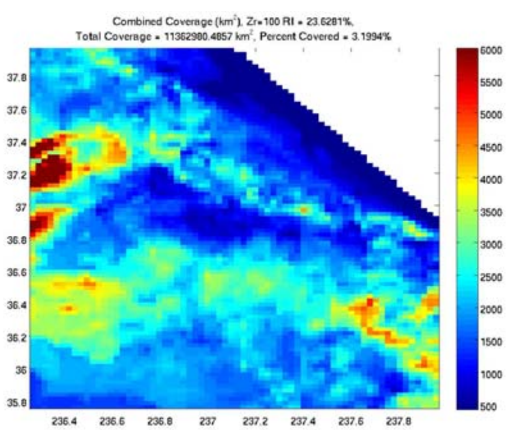

Figure 5. Coverage computed using combined analysis at 100m for 75Hz.

Table 1. Comparisons of adiabatic, non-adiabatic and combined coverages for each receiver depth (75Hz).

Zr(m)	RI Coverage	RD Coverage	Combined Coverage
50	7.64	3.59	4.03
100	4.76	3.19	3.20
150	3.94	2.81	2.85
200	3.46	2.64	2.68
250	3.18	2.49	2.52
300	2.80	2.32	2.34
500	2.09	1.88	1.84
750	1.59	1.50	1.50
1000	1.62	1.60	1.59
2000	4.08	4.12	4.08

IV. CONCLUSIONS

A viable method has been presented to decrease the time it takes to compute acoustic properties for area-wide analysis. This method, depending on the environment and the exercise objectives, has been shown to achieve up to 41% reduction in run time while maintaining an acceptable level of accuracy. More time savings can be achieved by adjusting the parameters of the algorithm based on the environmental complexity and the exercise objectives.

ACKNOWLEDGMENTS

The authors appreciate and acknowledge the funding support from the Naval Research Laboratory Base Program.

BIBLIOGRAPHY

Barron, C. N., L. F. Smedstad, R. C. Rhodes, B. Kara, C. D. Rowley, R. A. Allard, H. E. Hurlburt, "Validation of the 1/8 degree global Navy Coastal Ocean Model nowcast/forecast system," NAVO MSRC Navigator, 2004.

Collins, M. D., "Applications and time-domain solution of higher-order parabolic equations in underwater acoustics," *J. Acoust. Soc. Am.*, **86** (3), 1097-1102, 1989

Dennis, Steven M. and K. P. Hemsteter, "Coverage Metric for Acoustic Receiver Evaluation and Track Generation," submitted to IEEE Oceans, Vancouver, 2007

Fulford, James, "Broad geoacoustic assessment of some regional areas," Naval Research Laboratory Technical Report , 1993.

Gupta, Madan M., Liang Jin and Noriyasu Homma, *Static and Dynamic Neural Networks – From Fundamentals to Advanced Theory*, Chapter 6, IEEE Press, Wiley-Interscience, John Wiley and Sons, Inc., Hoboken, New Jersey, 2003.

Leslie, Wayne G. "AOSN II/Monterey Bay 2003," http://people.deas.harvard.edu/~leslie/AOSNII/index.html, 2003.

NAVO (Naval Oceanographic Office), "Digital Bathymetric Data Base Variable Resolution (DBDB-V) Version 5.2 Level 0", Oceanographic and Atmospheric Master Library (OAML), 24 May 2007.

Porter, Michael B. “The KRAKEN Normal Mode Program”, SACLANT Undersea Research Center, May, 2001.

Smith, George, “Bounded Elliptical Modes,” Naval Research Laboratory, Code 7183 unpublished manuscript, April 2004.

Urick, R. J. (1983). *Principles of Underwater Sound* (3rd ed.). New York: McGraw-Hill.